RAPID CYCLOGENESIS OVER THE GREAT BASIN, APRIL 22–23, 1958

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1. INTRODUCTION

The 0000 GMT surface chart for April 22, 1958, gave the first indications of formation of a surface Low near Wendover, Utah, in the Great Basin. Just 12 hours later it was evident that a storm of major proportions was developing, for central pressure of the Low dropped 17 mb. and the circulation about the center extended over the entire western third of the Nation.

The variety of bad weather produced by this storm, particularly in its early stages, ranged from dust storms in the southern Great Plains to record-breaking snowstorms in the mountainous sections of Montana and Wyoming. Some details of the weather conditions and of record-breaking occurrences are given in section 5. The rapid development of the Low, however, was the most spectacular feature of this storm and this paper is primarily concerned with discussion of significant factors contributing to the cyclogenesis.

2. BROAD-SCALE FEATURES

Comparison of 500-mb. charts for 1200 GMT on April 20 and April 21 (figs. 1a, 1c) shows the remarkable change in the upper-air flow pattern over the eastern Pacific and Gulf of Alaska during one 24-hour period. The sequence of (1) essentially simple southwest flow, (2) a split in the westerlies with its resultant cutoff Low, and (3) repositioning of the major jet axis into a northwesterly current, is not uncommon in this area, but the brief period of time required for the complete transition is noteworthy. We shall show how the requisite factors for cyclogenesis in the western United States, though obscure at 1200 GMT on April 20, became apparent on the 1200 GMT charts of April 21.

Long-wave trough positions prior to April 20 were: (1) off the east coast of Asia, (2) near the 160° W. meridian, and (3) in the central United States. Average wavelength between troughs was 70° of longitude. A new long-wave trough position was established east of the Kamchatka Peninsula by the vigorous deepening of a short-wave trough which moved into that area. The resulting shorter wavelength between the Kamchatka trough and the trough at 160° W. necessitated readjustment of the long-wave trough positions downstream, with the Kamchatka trough acting as an "anchor trough."

Constant absolute vorticity trajectories were computed from points along the southwest flow on the east side of the Kamchatka trough. The average of these trajectories, when superimposed on the 500-mb. chart for 1200 GMT of the 20th (fig. 1a), suggested the "shear and reamalgamation" process for readjustment of the long-wave trough positions, with a new position established over the western United States in approximately 48 hours. This process has been discussed and illustrated by Namias [1]. "Overshooting" of the strong southwesterly winds from the Kamchatka trough [2] across the sharply curved contours of the central Pacific ridge produced an eastward shearing effect on the northern portion of the trough at 160° W. The northern branch of the westerlies consequently increased and cut off the lower portion of the trough. The southern branch of the westerlies weakened and eventually became restricted to circulation around the newly-formed cutoff Low. The 300-mb. jet-stream axes as shown in figures 1 and 2 clearly depict the changes in relative strength and position of the two branches of westerly flow.

The second half of the process, "reamalgamation," followed the breakthrough of the northern branch of the westerlies. The ridge over the Aleutians (fig. 1b) moved into the Gulf of Alaska in response to the advection of warmer air and anticylonic vorticity into this region, while similar advection occurred in southeasterly current which developed on the northeastern side of the cutoff Low (fig. 1d). Thus the two ridges, one from the west and the other from the south, combined to produce strong anticyclogenesis over the Gulf of Alaska.

With the elimination of the long-wave trough position at 160° W. through the process discussed above, the resulting wavelength between the Kamchatka long-wave trough and the long-wave trough in the central United States was in excess of the stationary value required by the Rossby wave formula, suggesting that a major readjustment of waves was necessary. This readjustment of the super-stationary wavelength was effected through what Cressman [3] terms "discontinuous retrogression." Comparison of the 0000 GMT 500-mb. charts for April 21, 22, and 23 (figs. 1b, 1d, and 2b) shows how the long-wave trough position, which was over the central United States, retrograded to the Plateau Region. The anticyclogenesis in the Gulf of Alaska, combined with the necessity for retrogression of the long-wave trough position from the central United States, provided a field of motion favorable for the plunging of a cyclonic vorticity maximum and associated pool of Arctic air from Alaska southeastward

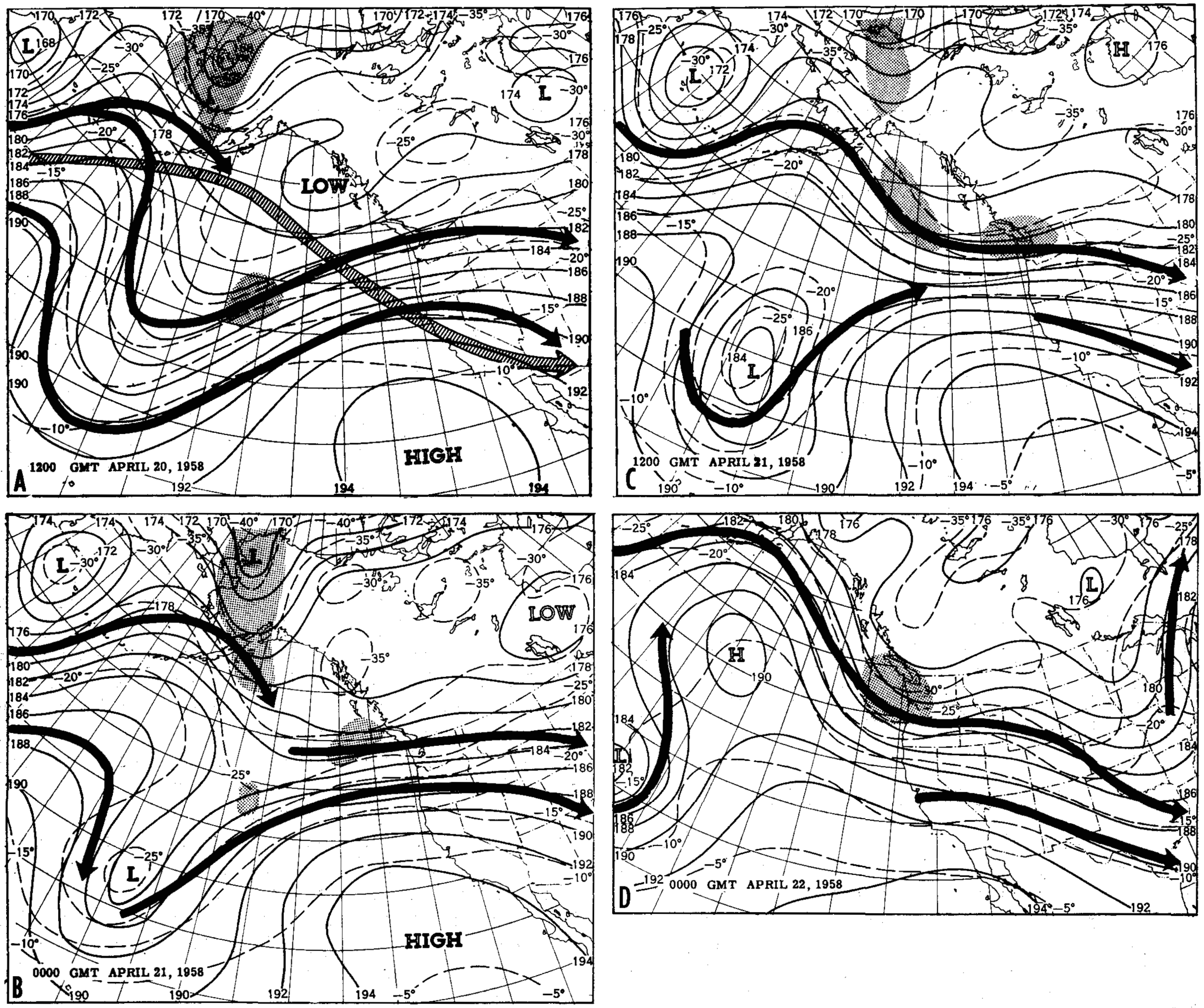

FIGURE 1.—500-mb. charts. (a) 1200 GMT, April 20, (b) 0000 GMT, April 21, (c) 1200 GMT, April 21, and (d) 0000 GMT, April 22, 1958. Contours (solid lines) at intervals of 200 geopotential feet; isotherms (dashed lines) at intervals of 5° C.; and areas of absolute vorticity (shaded) greater than 150×10^{-6} sec.$^{-1}$. 300-mb. jets denoted by heavy arrows. Hatched arrow in (a) represents average constant absolute vorticity trajectory.

into the Great Basin. In its broad-scale evolution, this situation was strikingly similar to the outbreak of Arctic air into the Pacific Northwest during November 1955 [4], [5].

3. VORTICITY CONSIDERATIONS

To show more clearly the source and development of the 500-mb. trough which preceded the surface development, the movement of areas of maximum cyclonic absolute vorticity at 500 mb. were tracked (fig. 3). Absolute vorticity charts were prepared by the Joint Numerical Weather Prediction Section of the National Meteorological Center for 12-hour intervals from 1200 GMT, April 20 through 0000 GMT, April 24. On the 500-mb. charts in figures 1 and 2, areas of absolute vorticity in excess of 150×10^{-6} sec. $^{-1}$ are shaded. The distribution of these vorticity maxima in the 500-mb. flow pattern shows quite plainly the movements and tendencies of the upper-air troughs associated with the surface cyclogenesis.

The apparent effect of the cyclonic vorticity maximum which moved northeastward out of the Pacific trough [1] was temporary retardation and flattening of the ridge building off the west coast. The short-wave trough in Alaska on April 21 moved southeastward into the portion

[1] In the following discussion the trough near 160° W. longitude will be referred to as the Pacific trough.

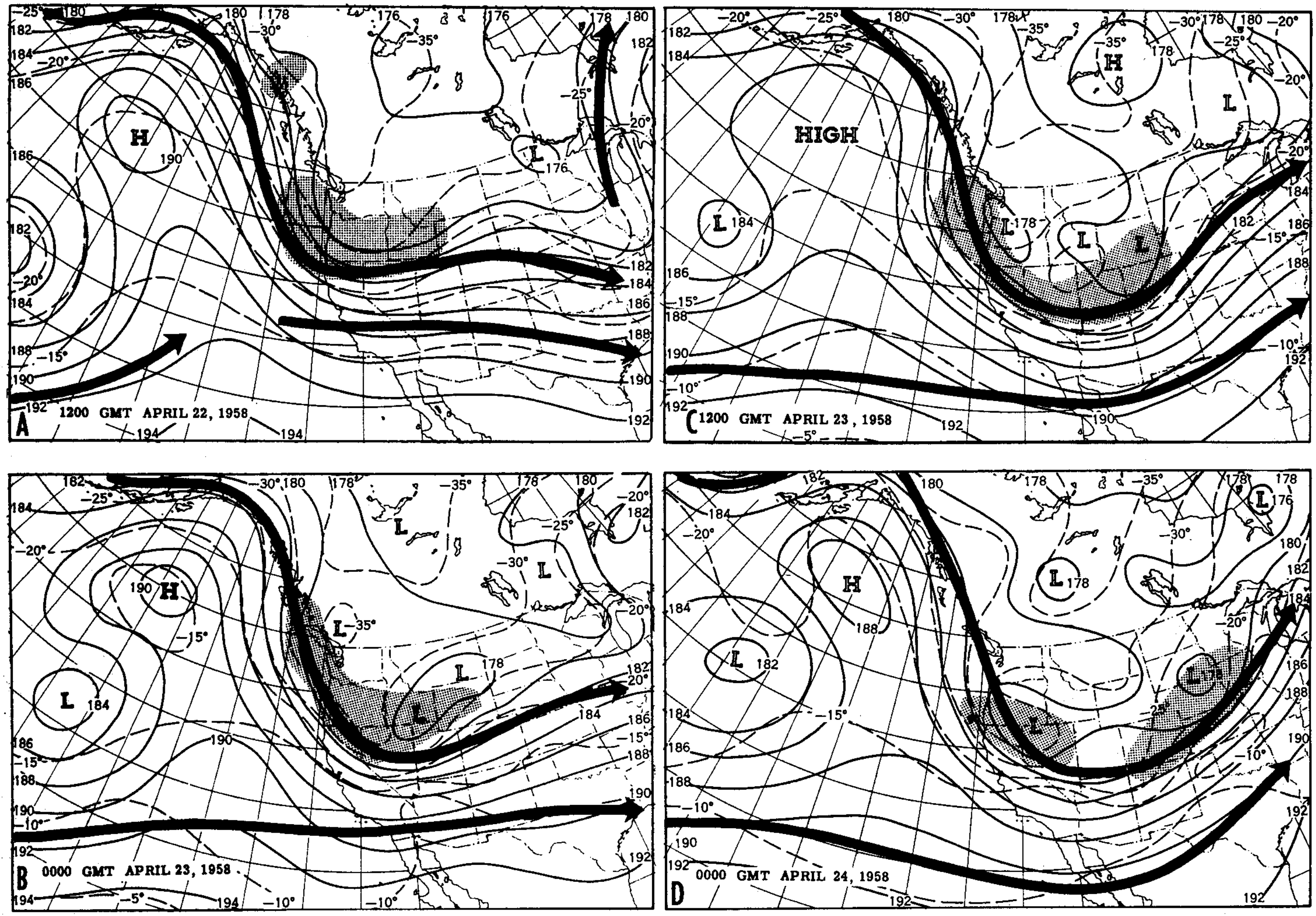

FIGURE 2.—500-mb. charts. (a) 1200 GMT, April 22, 1958. (b) 0000 GMT, April 23, (c) 1200 GMT, April 23, and (d) 0000 GMT, April 24. 300-mb. jets denoted by heavy arrows and areas of maximum absolute vorticity shaded.

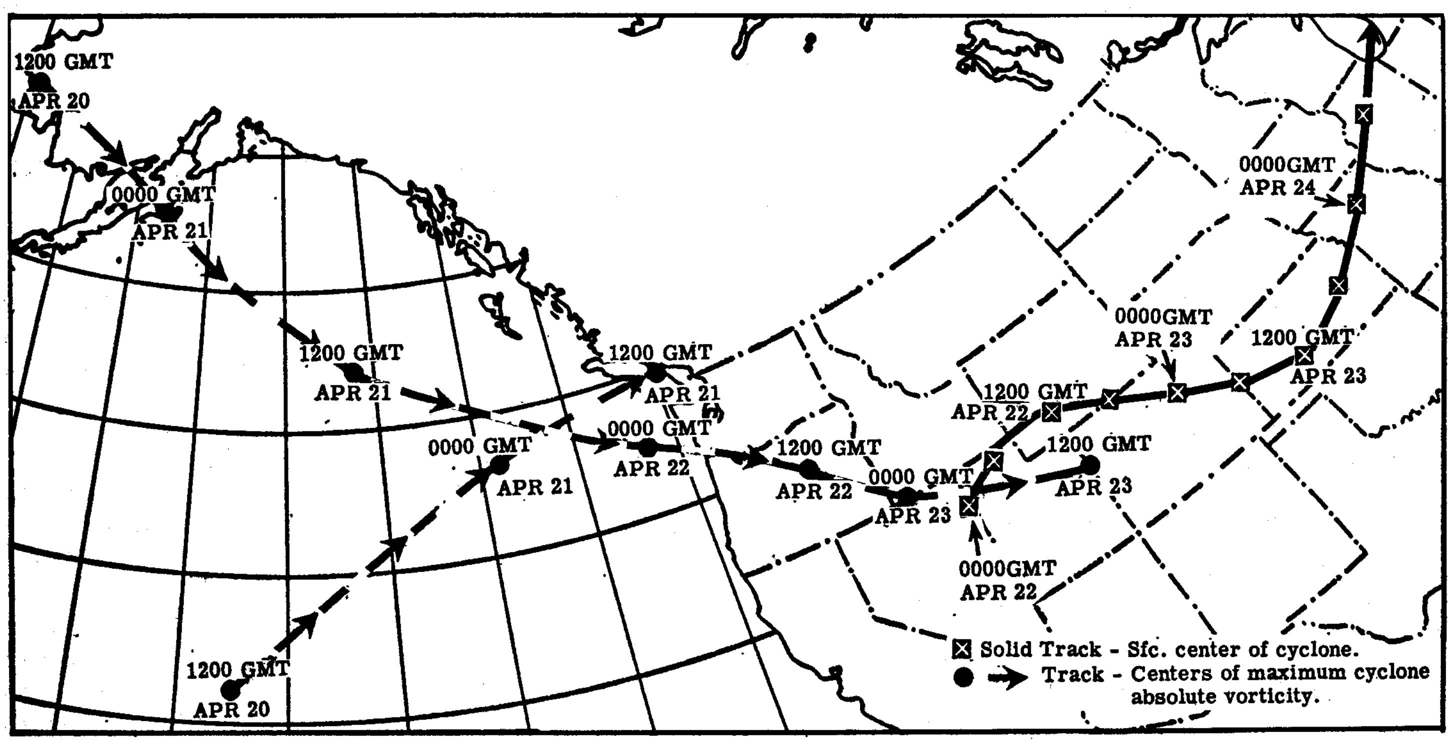

FIGURE 3.—Tracks of centers of areas of maximum absolute vorticity (dashed lines), 1200 GMT, April 20 to 1200 GMT, April 23, 1958, and track of surface Low (solid line), 0000 GMT, April 22 to 0600 GMT, April 24, 1958.

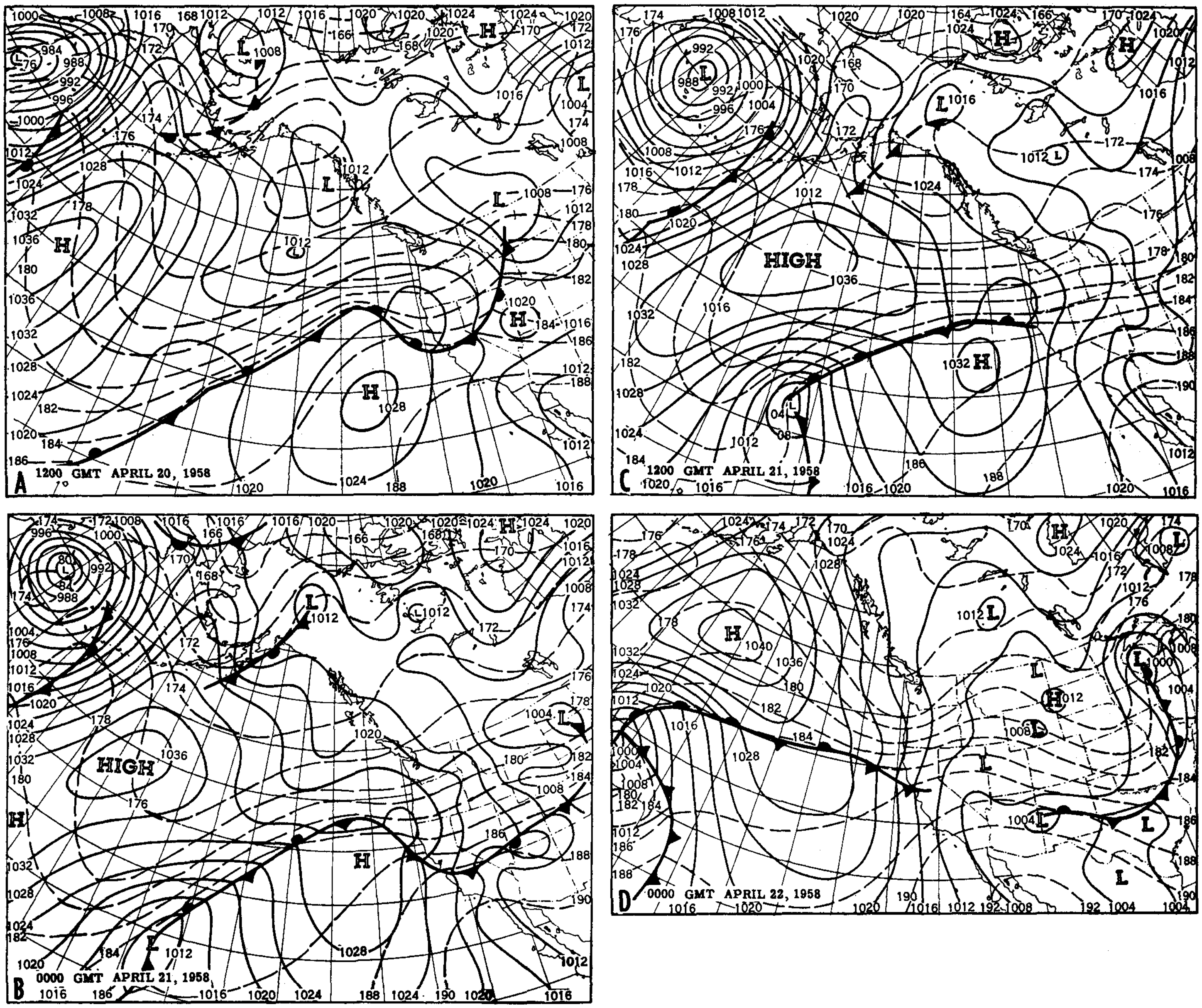

FIGURE 4.—Surface synoptic charts with 1000–500-mb. thickness lines (dashed). (a) 1200 GMT, April 20, (b) 0000 GMT, April 21, (c) 1200 GMT, April 21, and (d) 0000 GMT, April 22, 1958.

of the ridge which had been weakened by advection of cyclonic vorticity from the Pacific trough. Thus a strong concentration of cyclonic vorticity was propagated off the coast of Washington on April 22 (fig. 2a), just prior to the spectacular surface development downstream during the following 24 hours.

4. SURFACE DEVELOPMENT

For a week or more prior to April 20, zonal flow in the upper troposphere steered surface systems from the Pacific into the North American continent in the vicinity of the United States-Canadian border with some semblance of regularity. With the abrupt change in the upper-level flow from zonal to meridional on April 21, the surface picture also changed quite markedly (fig. 4). The progression of surface Lows across the west coast was completely eliminated by the block in the Gulf of Alaska, which was reflected at the surface by the 1040-mb. High in the vicinity of Ship "P" (50° N., 145° W.) on April 22 (fig. 4d). A lobe of this High, extending southward along a northwest-southeast axis, dominated the surface picture for the remainder of the month in the area off the west coast of North America. Inland, the surface chart presented a rather nondescript collection of small Highs and Lows in the western United States.

As the 500-mb. trough, and its associated vorticity maximum, moved southeastward from Alaska, surface pressures began falling in the Pacific Northwest about 1800 GMT on the 21st. During the following 6 hours the isallobaric fall center moved southeastward to the Great

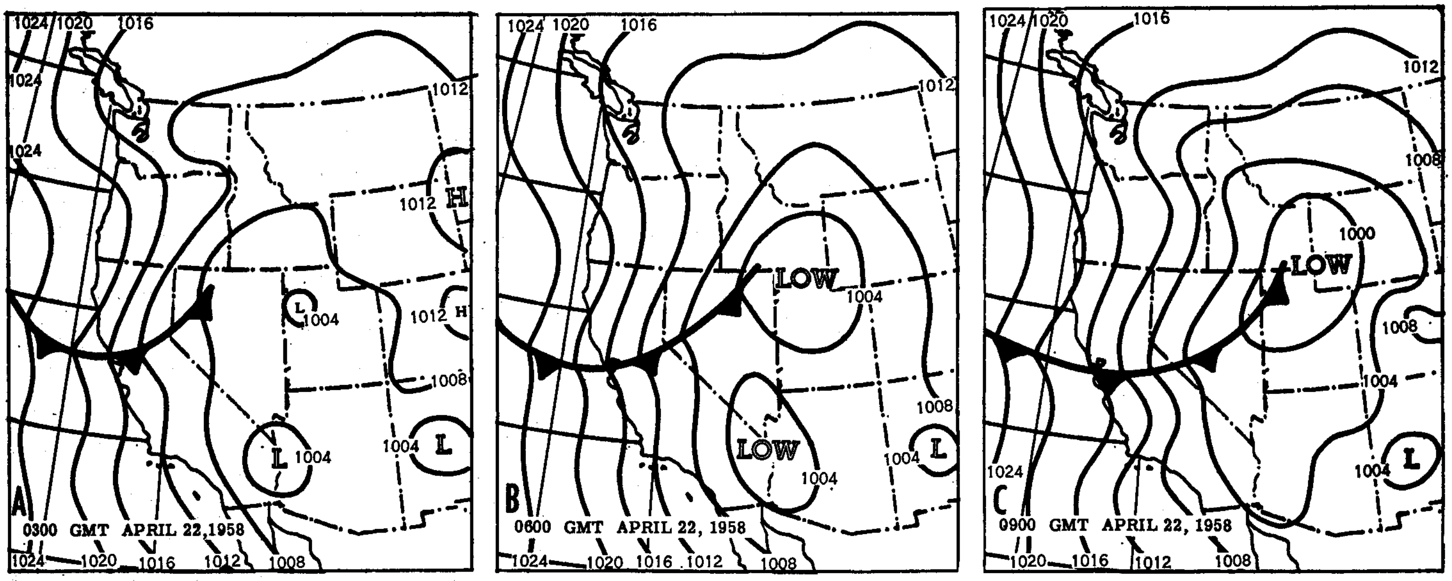

FIGURE 5.—Sectional surface synoptic charts. (a) 0300 GMT, April 22, (b) 0600 GMT, April 22, and (c) 0900 GMT, April 22, 1958.

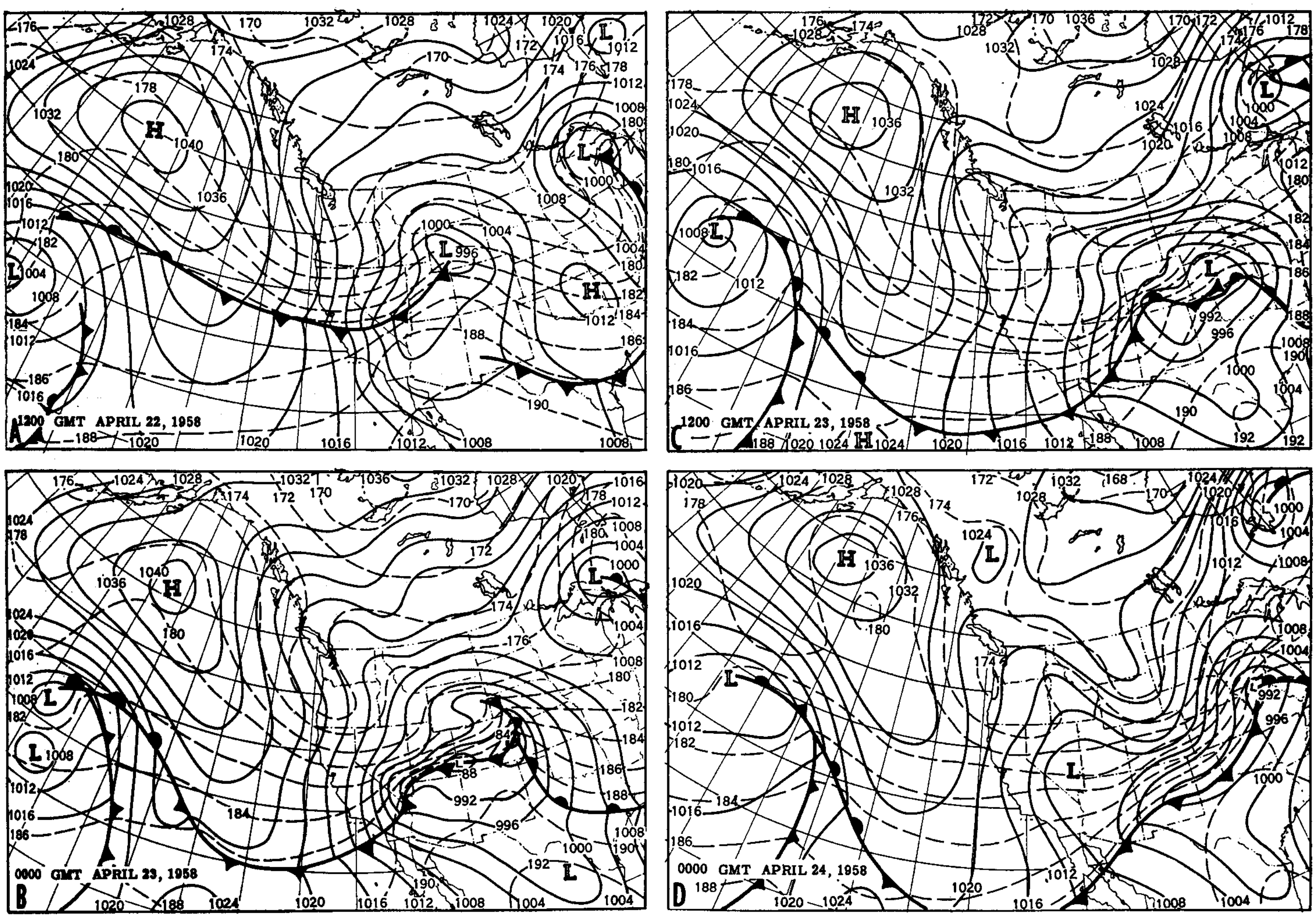

FIGURE 6.—Surface synoptic charts with 1000–500-mb. thickness lines (dashed). (a) 1200 GMT, April 22, (b) 0000 GMT, April 23, (c) 1200 GMT, April 23, and (d) 0000 GMT, April 24, 1958.

Basin and 3-hourly pressure falls of 3 to 4 mb. were reported from most stations in this region. The first closed circulation of the new storm, although it probably was not recognized as such at the time, appeared on the 0000 GMT surface chart for April 22 just south of Wendover, Utah (fig. 4d). Central pressure at this time was 1009 mb. The series of sectional surface charts for intermediate synoptic hours (fig. 5) shows development during the next 12 hours. By 1200 GMT, April 22 (fig. 6a), the Low had moved eastward into southwestern Wyoming and deepened to a 992-mb. center, a remarkable fall of 17 mb. in just 12 hours.

Meanwhile, a weak cold front through central California, a remnant of a frontal system which passed through the Plateau during the preceding 36 hours, became revitalized and extended into the developing Low (fig. 6a). The 1,000–500-mb. thickness gradient to the north of the cold front increased markedly in response to the strong cold air advection associated with the deepening upper trough. The sharp discontinuity of the thickness gradient across the front is shown very well in figures 6a-d.

The storm attained its greatest development in eastern Colorado at 0000 GMT, April 23 (fig. 6b), with a central pressure of 982 mb. During the 24-hour period after this time the Low became complex, when several small perturbations developed along the front as reflections of the disorganized upper-level features (possibly complicated by irregular terrain) depicted in figure 2c. By 0000 GMT on the 24th, however, both the upper-level and surface Lows had become organized into single vortices and had begun to curve northeastward toward the Great Lakes.

5. ASSOCIATED WEATHER

Some features of the weather associated with this storm are briefly described in [6]. The influx of cold air behind the Low as it moved northeastward brought freezing temperatures to much of the Rocky Mountain and Great Plains States on the 23d. A good example of the sharp thermal contrast across the cold front occurred in Kansas where maximum temperatures in the 90's (° F.) were reported ahead of the front in the eastern part of the State while Goodland, in northwestern Kansas, reported a new record late season minimum of 21° F.

Precipitation accompanying the storm was both widespread and varied. Rain and drizzle fell ahead of the warm front and thunderstorms with hail, freezing rain, and snow were reported behind the cold front. Strong winds in the warm sector raised dust storms from Arizona to Oklahoma. South-central Montana and the Big Horn Mountain region of Wyoming had one of the heaviest snowstorms on record April 23 and 24. Up to 3 feet of new snow was reported from the Big Horn Mountains, near Sheridan, Wyo., and in Montana, Red Lodge received 55 inches, and Nye and Mouat Mine 60 inches.

Table 1 lists weather occurrences with this storm that equalled or broke prior records.

Table 1.—*Weather occurrences with storm of Apr. 22–23, 1958, that equalled or broke prior records.*

Place	Date	Weather occurrence
Lincoln, Nebr.	22–23	1.38 in. Greatest 24-hour precipitation amount since 1944.
Sheridan, Wyo.	22–23	Heaviest snowstorm of record so late in month of April.
Winslow, Ariz.	23	29.19 in. Lowest pressure ever recorded at this station.
Salt Lake City, Utah	23	15 in. Heaviest 24-hour April snowfall on record.
Helena, Mont.	24	20° F. Minimum temperature record for date.
Goodland, Kans.	24	21° F. Record late season low temperature.
Topeka, Kans.	25	36° F. Minimum temperature for date equalled record established in 1907.

ACKNOWLEDGMENT

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REFERENCES

1. J. Namias, "Thirty-Day Forecasting: A Review of a Ten-Year Experiment," *Meteorological Monographs*, vol. 2, No. 6, American Meteorological Society, Boston, 1953, 83 pp. (p. 61–62).
2. J. F. O'Connor, "Practical Methods of Weather Analysis and Prognosis," *NAVAER* 50–1P–502, U. S. Office of Naval Operations, 1952, 126 pp. (p. 81).
3. G. P. Cressman, "On the Forecasting of Long Waves in the Upper Westerlies," *Journal of Meteorology*, vol. 5, No. 2, Apr. 1948, pp. 44–57 (p. 53).
4. J. F. O'Connor and C. R. Fean, "The Record-Breaking Cold Wave of Mid-November 1955 in the Northwest," *Monthly Weather Review*, vol. 83, No. 11, Nov. 1955, pp. 279–291.
5. L. A. Hughes and D. W. Saxton, "An Application of Long-Wave Principles to a Cold Outbreak," *Bulletin of the American Meteorological Society*, vol. 38, No. 6, June 1957, pp. 329–334.
6. U. S. Weather Bureau, *Weekly Weather and Crop Bulletin, National Summary*, vol. XLV, No. 17, April 28, 1958.